Evaluarea eficienței nisipului dune ca adăugare minerală pentru a produce beton fibră ultra-performante

Assessing the effectiveness of dune sand as a mineral addition to produce ultra-high performance fiber reinforced concretes

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Rezumat. *În scopul valorificării resurselor noastre naturale, în special a nisipului dunărean, au fost studiate dezvoltarea și caracterizarea forței de beton cu fibre de înaltă performanță pe bază de adaosuri minerale locale. Studiul experimental a fost realizat pe diferite betoane realizate din nisip dunătic fin măcinat și armate cu fibre metalice (la procente diferite) în comparație cu alte betoane fabricate cu materiale pe bază de ciment (pământ de silice și puzolan). Betoanele studiate au fost fabricate din ciment Portland (PC), nisip dune (DS), pozzolan (PZ), nisip fin (FS), fibre metalice (MF) și aditivi super plastifiant (SP). Rezultatele obținute arată posibilitatea obținerii unui beton din fibre mai performant având 34 MPa pentru tracțiune la încovoiere și 136 MPa pentru rezistența la compresiune. Imaginile SEM ale betoanelor studiate au arătat efectul benefic al nisipului duză zdrobită asupra produselor de hidratare pe bază de ciment, oferind noi produse de hidratare din reacția pozzolanică dintre nisipul duzic zdrobit și portlanditul (Ca (OH) 2) eliberat din hidratarea cimentului. Pentru fabricarea unui beton bazat pe materii prime locale care au caracteristici mecanice bune, poate duce la economisirea consumului de ciment.*

Cuvinte cheie: Materii prime locale, nisip de dune, fibre de înaltă performanță (UHPFC), performanță mecanică și rezistență la compresiune

Abstract. *In order to valorize our natural resources especially dune sand, the strength development and characterization of ultra-high performance fiber concrete based on local mineral additions, have been studied in this present work. The experimental study was carried out on various concretes made from finely ground dune sand and reinforced with metal fibers (at different percentages) compared to others concretes manufactured with cementitious materials (silica fume and pozzolan). The studied concretes were made*

from Portland cement (PC), dune sand (DS), pozzolan (PZ), fine sand (FS), metal fibers (MF) and super plasticizing admixture (SP). The results obtained show the possibility to producing a more performant fiber concrete having 34 MPa for flexural tensile and 136 MPa for compressive strength. SEM-images of studied concretes showed the beneficial effect of the crushed dune sand on cementitious hydration products giving of new hydration products from the pozzolanic reaction between crushed dune sand and portlandite (Ca(OH)2) released from hydration of cement. To manufacture a concrete based on local raw materials having good mechanical characteristics, can lead to saving the consumption of cement.

Key words: Materii prime locale, nisip de dune, fibre de înaltă performanţă (UHPFC), performanţă mecanică şi rezistenţă la compresiune

1. Introduction

In Algerian, the dune sand occupies about 6% of Sahara area and which covers about a third of the African continent [1-5]. Dune sand is known a product of the slow disintegration of rocks by erosion agents such as air, rain and so, etc. Several investigation have already confirmed that dune sand have a pozzolanic reactivity and can be used as a supplementary cementitious material to manufactured cement mortars of concretes [4-9]. However, research conducted to date are few and do not assess performances of concrete with this mineral type which it is a key issue for again further research on this. It could cite many researches on the use of dune sand in cement mortars/concretes [10-12].

However, the technological evolution of the concretes has made it possible to develop new concretes more efficient and having high mechanical characteristics so called Ultra-High Performance Fiber Reinforced Concretes (UHPC) [8-9]. Nevertheless, from a practical point of view of formulation of these concretes requires adequate components and a good mastery of composition parameters such as the W /C ratio, the binder mixture, etc. Because this binder ratio must be lower in order to achieve the best mechanical performances. That's why researchers continue to find others adding for to substitute totally the silica fume in the UHPC composition to make it less expensive material [12-15]. Work investigates have also been carried out on the use of pozzolanic additions in UHPFRC, in order to obtain high performance mechanical concretes. It can be cited the dune sands and they are one of the supplementary cementitious materials known by characteristics that allow it to be used in new concrete. A very detailed study was previously carried on the valuation of sand dunes in the formulation of UHPFRC [10-11]. The results showed that the sand may have a pozzolanic addition character and can be used in the formulation of the concrete without disrupting performance.

For this purpose, the work aim is to evaluate potential of the sand dune as a supplementary cementitious material (by total substitution of silica fume) in order to produce an ultra-high performance concrete (UHPC) with less expensive material. The experimental study was carried out on various concretes made from finely ground dune sand and reinforced with metal fibers (at different percentages) compared to others

concretes manufactured with cementitious materials (silica fume and pozzolan). The studied concretes were made from Portland cement (PC), dune sand (DS), pozzolan (PZ), fine sand (FS), metal fibers (MF) and super plasticizing admixture (SP).

2. Experimental Program

2.1. Used materials

Cement (PC): The cement used is CEM I 52.5 cement type; density of 3160 kg/m^3 and Blaine surface of 4800cm^2/g. The physical, chemical and mineralogical characteristics are given in Table 1, and are according to standard NF EN 197-1 standard.

Sand of dunes (SD): In this work sand dune finely ground up to a fineness of 4000cm2/g is used in substitution in cement on the one hand and as fine added in the formulation of concretes another part.

Natural pozzolana (PZ): Pozzolan was introduced in the composition of fibred concretes as fines in order to see the effect to fines on the mechanical performance of UHFC.

Fine sand (FS): For the sand, it was opted for quarry sand from the Bouzegza region sieved on 2 mm sieves, 76% of sand equivalent and an expansion of 23.3%.

Superplasicizer (SP): In order to reduce the W/B ratio and increase the fluidity of the concretes for ease of implementation while maintaining a high level of performance, it was used a super high temperature plasticizer Tempo12 type water reducer manufactured by Sika according to the standard EN934-2.

Metallic fibers (MF): The metal fibers are introduced to have better strengths and ductile behavior.

Table 1 Characteristics of cementitious materials

Minerals	Sand dune (SD)	CEM I 52.5 (CP)	Pozzolan (PZ)
Chemical composition			
SiO_2	94.40	20.03	41.00
Al_2O_3	2.23	5.07	14.58
Fe_2O_3	0.33	3.43	10.83
CaO	0.45	62.43	11.08
MgO	0.06	1.64	4.22
SO_3	0.17	2.57	-
K_2O	1.13	0.59	-
Na_2O	0.36	0.04	-
P_2O_5	0.01	0.15	-
TiO_2	0.04	0.21	-
P.A.F	0.82	3.81	12.80
Mineralogical composition			
C_3S	-	62.89	-
C_2S	-	10.33	-
C_3A	-	7.64	-
C_4AF	-	10.43	-
Physical properties			
Specific mass (g/cm^3)	2.95	2.93	3.25
Specific surface (cm^2/g)	4000	4800	4004

Table 2 Characteristics of metal fibers

Properties	Metallic fibers
Length (mm)	30
Diameter (mm)	0.55
L/D	55
Density (g/cm^3)	8.38
Tensile strength (MPa)	1100

2.2. Methodology of work

The study was divided into two parts. Foremost, the work involves studying the effect of finely ground dune sand (5, 10, 15 and 20%.wt of cement) by replacement of cement on the rheological behavior of cementitious pastes used for studied concretes. In this case, the amount of used superplasticizer has been adjusted to ensure adequate fluidity and avoid segregation. Second work part was realized on the ultra-high performance concretes (UHPC) with an optimal percentage of finely ground dune sand substituted of cement by measuring the mechanical strength at 2, 7 and 28 days. Then, optimization of UHPFC at 0.2, 2, 3.5 and 5% metal fiber percentages of both UHPC1 and UHPC2 variants while measuring of mechanical strength also at 2, 7 and 28 days. After optimizing the percentage of sand substitution and fibers, the best variant was determined with the best mechanical properties at 28 days. Finally, non-destructive ultrasonic tests at 7, 14, 21 and 28 days were carried out on concretes with better results in order to verify the compactness provided by sand dune.

2.3. Test methods

Rheological tests: The rheological tests were carried out using a viscometer of VT550 type with a coaxial cylindrical geometry. The rheological measurements were carried out according to the following protocol (Firstly: a pre-shearing and ramping shear rate at 350s-1 for 60s. Second step: maintaining a constant shear rate at 350s-1 for 300s). All of the comments tested were prepared with a fixed superplasticizer dosage and a W/C ratio of 0.29 which is kept constant [12].

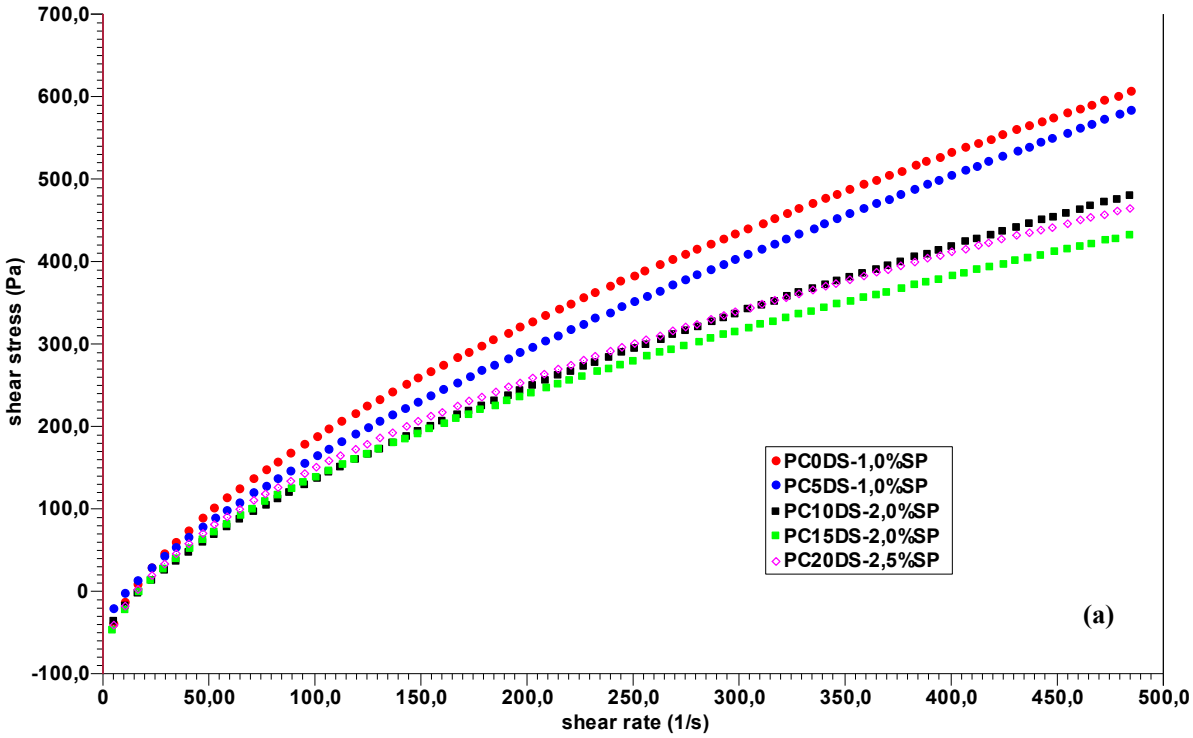
Mechanical tests: After mixing, for each mixture, specimens of 4×4×16 cm3 were prepared according to standard NF EN 196-1. The test specimens were demolded after 24 h and then cured in water. The compressive and flexural strengths of cement mortar specimens were tested at three different ages of 1, 7 and 28 days by using a uniaxial hydraulic compression machine under a load control rate of 0.20 MPa/s. Three-point bending tests were carried out on prismatic samples according to ASTM C348 [13]. Half samples were subjected to compressive stress by using a hydraulic press with a capacity of 3000 KN according to ASTM C349 [14].

3. Results and discussion

3.1. Rheological study

Figure 1a and 1b show the variation of viscosity and shear stress of studied cementitious pastes at different superplasticizer dosages as a function of shear rate. It is clearly observed that the more SP-dosage increases more the cementitious pastes become the fluids [15-17]. However, cement pastes having high fluidity are betters for formulation of UHPC-concretes especially in presence of fiber. It was noted that more concrete is fluid more the addition of fibers is easy and is good their distribution in concrete matrix.

After having studied the rheological of cementitious pastes with various contents of superplasticizer in presence of crushed dune sand, it should be noted that SP effect is appreciably on the main rheological parameters (plastic viscosity and shear stress) of studied cement pastes. The results given in the rheograms show a non-Newtonian of cement pastes behavior which follows the Herschel- Bulkley model [15-17].



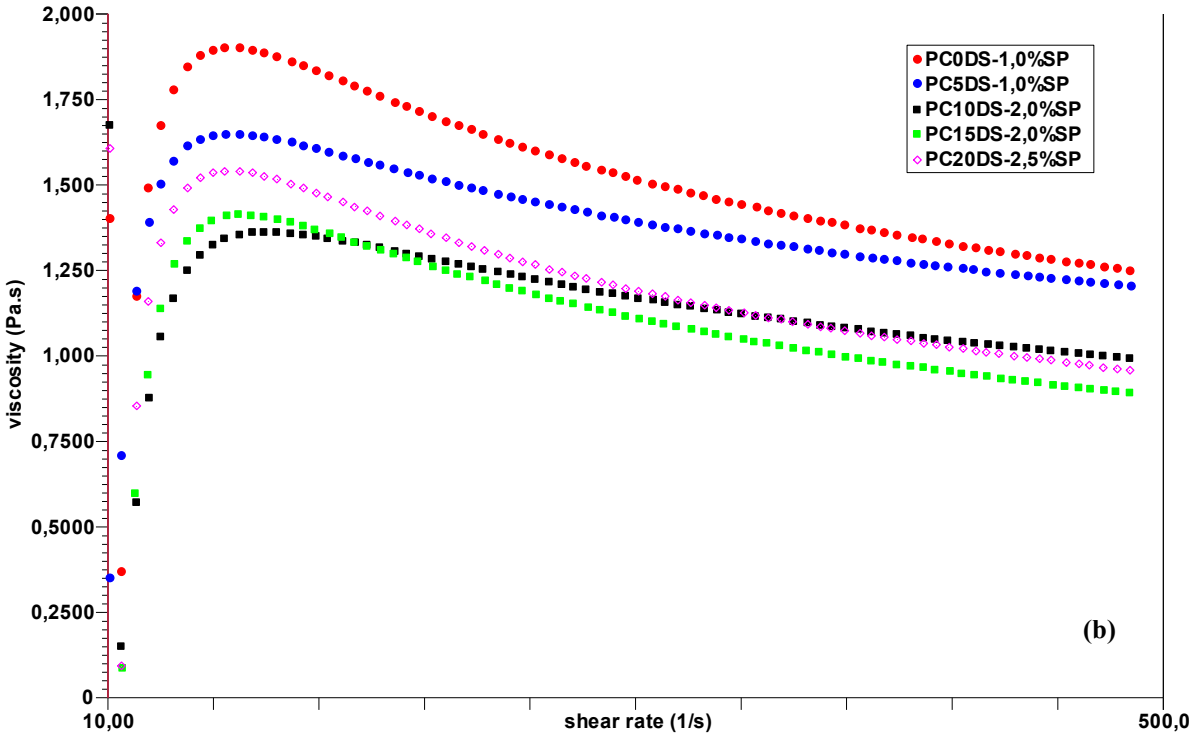


Figure 1 Shear stress (a) and viscosity (b) of cementitious pastes with different dosages of superplasticizer

With increasing of SP content a decrease of the viscosity and shear the stress was observed (figure). That can be explained by dispersing effect of SP which causes not only electrostatic effect but also steric repulsion between the cement particles by reducing their agglomeration thanks to the principal length of the superplasticizer chains as well as the grafting of the not adsorbed side chains. More SP content increases, more the cementitious pastes becomes more fluid having a Newtonian behavior, up to SP dosage. Beyond, superplasticizer does not effect on the cement pastes flow [16-17].

3.2. Effect of dune sand on the mechanical performances of UHPC

In this work part, ultra-high performance concretes (UHPC) with different percentage of finely crushed dune sand (DS) substituted of cement were elaborate. Table 3 gives the detail mixtures of studied concretes. Then mechanical strength has been measured at 2, 7 and 28 days in order to determine an optimal percentage of DS having a best mechanical strength.

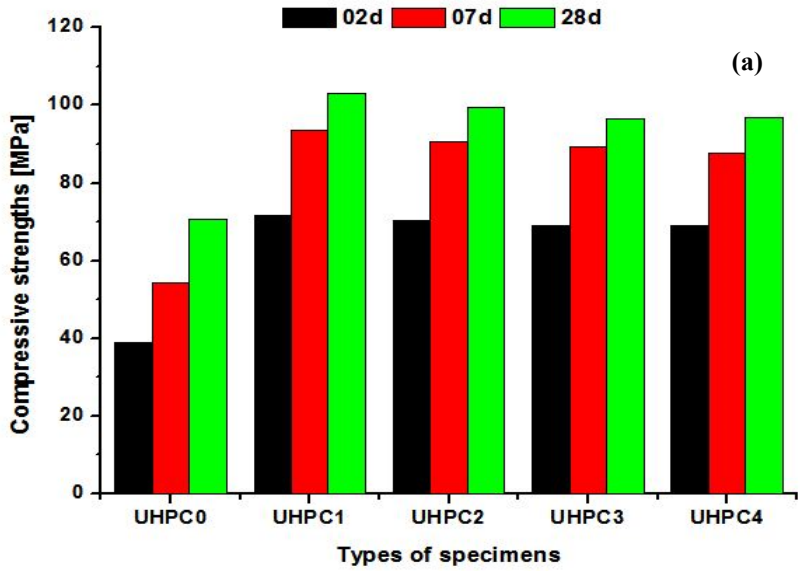
Table 3 Different compositions of ultra-high performance concretes (UHPC) with dune sand

Components	UHPC0	UHPC1	UHPC2	UHPC3	UHPC04
PC [Kg]	1000	950	900	850	800
SD [Kg]	148.8	148.8	148.8	148.8	148.8
SDS [Kg]	0	50	100	150	200
FS [Kg]	958	958	958	958	958
SP [Kg]	24.8	20.3	20.3	15	10
Water [Kg]	246.7	250.9	251.6	255.3	258.6
W/B	0.23	0.23	0.23	0.23	0.23

Table 4 Compressive and flexural Strength of UHPC with various percentages of DS

	Compressive strength [MPa]			Flexural strength [MPa]			% increase Compressive strength 28d	% increase Flexural strength 28d
	2d	7d	28d	2d	7d	28d		
UHPC0	39,07	54,20	70,66	8,02	10,14	11,23	-	-
UHPC1	71,76	93,64	103	13,27	14,31	15,62	45,77	39,09
UHPC2	70,21	90,55	99,6	12,07	13,50	14,59	40,96	29,92
UHPC3	68,94	89,20	96,32	13,53	14,78	15,11	36,31	34,55
UHPC4	68,87	87,73	96,98	12,93	14,47	14,90	37,25	32,68

From the figure 2 and table 4, it is observed that concrete specimens (UHPC1) at 5% of dune sand by cement replacement, showed compressive strengths an average greater than that concrete control (UHPC0). Beyond this, all concretes have a higher compressive strength than the reference concrete whatever the hardening age. Control specimens had the lowest strengths at all ages [8-10, 18]. It was noted that same observations were obtained for the results of flexural strength of all studied concretes.



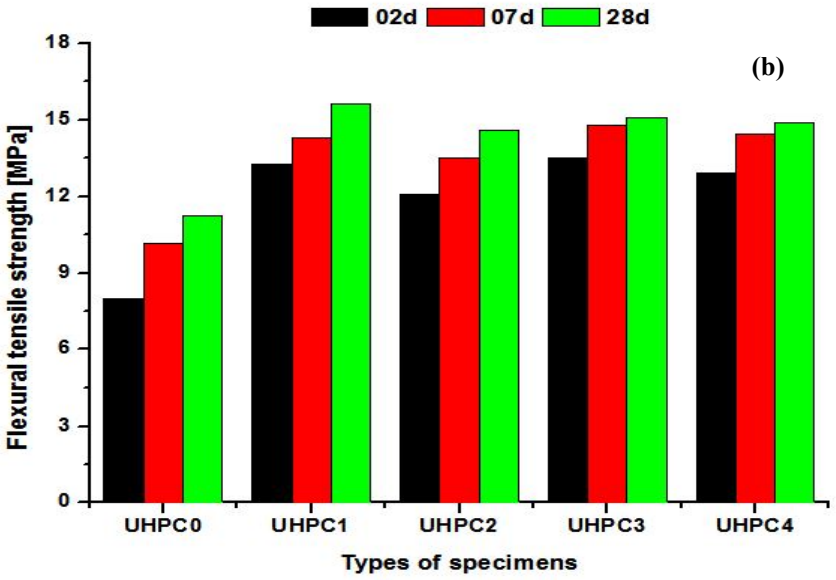
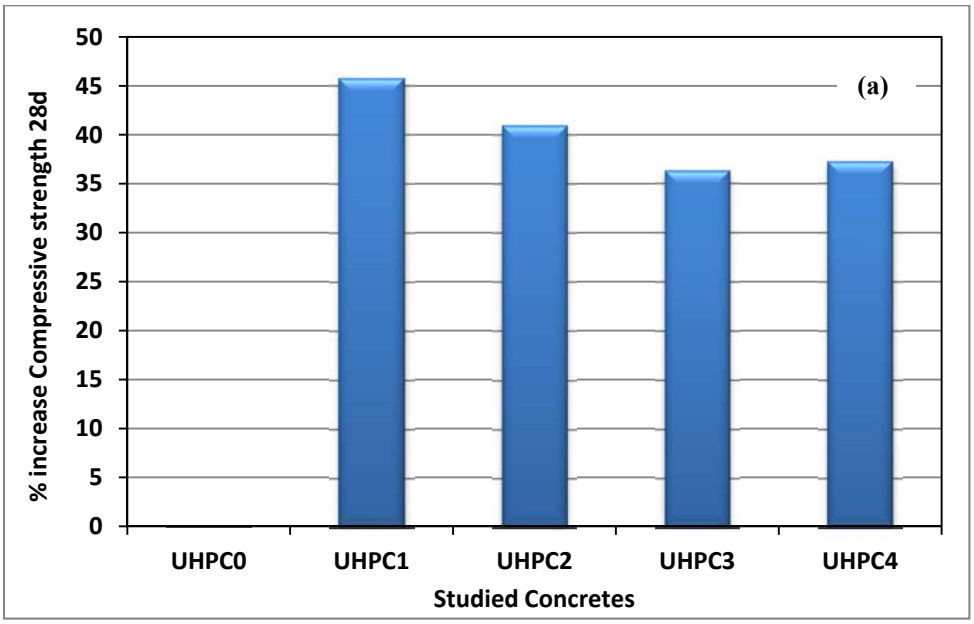


Figure 2 Compressive (a) and flexural (b) Strength of UHPC with various percentages of DS

In order to estimate the effect of dune sand on mechanical performances, improvement of compressive and flexural strength of studied concretes was given in figure 3 (a, b). Compared to control concrete UHPC0 (0 cement substitution), the average improvement is 35 at 45% for compressive strength (figure 3a) and 30 at 40% for flexural strength (figure 3b). This can be explained by the fact that the finely crushed of dune sand addition act on the hydration reactions by pozzolanic reaction of the previously well-dispersed cement grains with portlandit hydroxide, modifying their growth rates and their morphology [19-23].



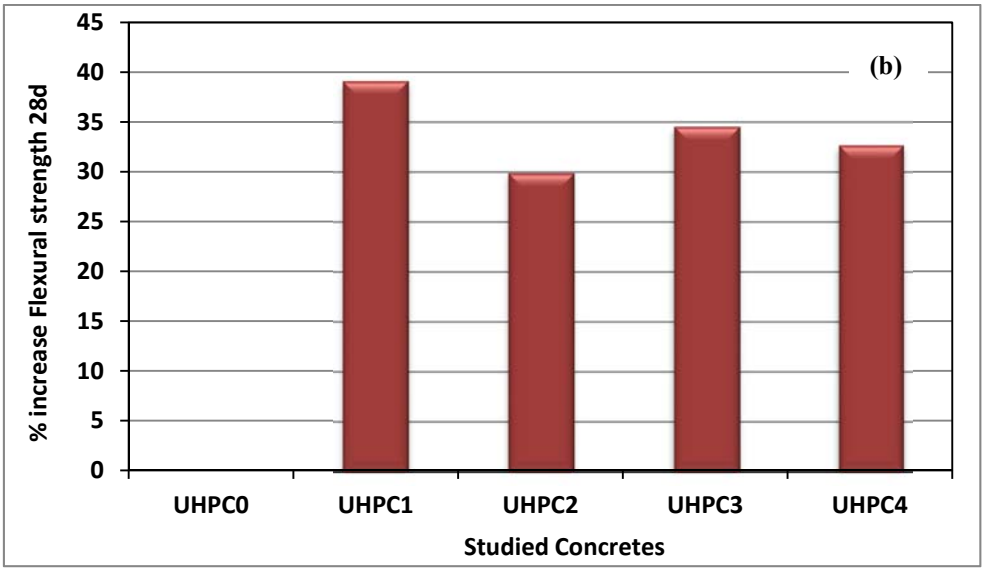


Figure 3 Improvement of the Compressive (a) and flexural (b) Strength of UHPC

Due to maneuverability, the addition of fibers occurs only in the first two UHPC1 and UHPC2 variants; UHPC3 and UHPC4 cannot accept fibers. To determine the amount of fiber needed for the various concretes, we proceeded to the percentage optimization of the fibers according to mechanical strength.

3.3. Effect of dune sand addition on reinforced fiber concretes

After estimating the role of dune sand as a pozzolanic material in formulation of high performance concretes, it is necessary to see effect this addition type in the presence of fibers. In this work part, the study was carried out on the Ultra High Performance Fiber Reinforced Concrete (UHPFC) made by metal fibers in order to evaluate the use of dune sand as a mineral addition. For this, concrete formulations were taken from the previously study part. As reinforcement, metallic fibers was chosen and used at different content in volume fraction of concrete (0.2, 0.2, 2, 3.5 and 5%). Metallic Fibers are therefore added to UHP-concretes based on dune sand to enhance the ductility of the material, in both tension and compression [23-27]. The mixture detail of UHPF-concretes is given in table 5.

Table 5 Mixture details of ultra-high performance fiber reinforced concrete UHPFC in 1m^3

Components	UHPFC1	UHPFC2
Cement PC [Kg]	950	900
Sand dune SD [Kg]	148.8	148.8
Crushed Sand dune CDS [Kg]	50	100
Fine Sand FS [Kg]	958	958
Metallic fibers (MF)* [%]	0,02	0,02
Superplasticizer SP [Kg]	20.3	20.3
Total water [Kg]	250.9	251.6
W/B	0.23	0.23

*fibers were introduced by fraction volume in %; 0.2, 2, 3.5 and 5%.

After measuring the compressive and flexural strength of studied concretes, the obtained results are given in table 6. Also, the gain and improvement (in %) of concrete strength are calculated and given in table 7.

Table 6 Compressive and flexural Strength of fiber reinforced concrete

		Compressive strength [MPa]			Flexural strength [MPa]		
	MF(%)	2d	7d	28d	2d	7d	28d
UHPFC1	**0.2**	77	93	104	13,50	14,10	15,11
	2.0	75	97	114	14,12	20,63	22,23
	3.5	77	105	125	13,88	25,66	30,27
	5.0	77	103	134	15,47	26,63	33,90
UHPFC2	**0.2**	80	92	105	14,65	14,77	15,17
	2.0	78	96	121	14,83	23,16	30,10
	3.5	77	100	126	14,80	25,68	32,53
	5.0	85	103	135	16,48	30,20	34,08

Table 7 % increase of Compressive and flexural Strength of UHPFC

	MF(%)	% increase Compressive strength 28d	% increase Flexural strength 28d
UHPFC1	**0.2**	-	-
	2.0	9,62	47,12
	3.5	20,19	100,33
	5.0	28,85	124,35
UHPFC2	**0.2**	-	-
	2.0	15,24	98,42
	3.5	20,00	114,44
	5.0	28,57	124,65

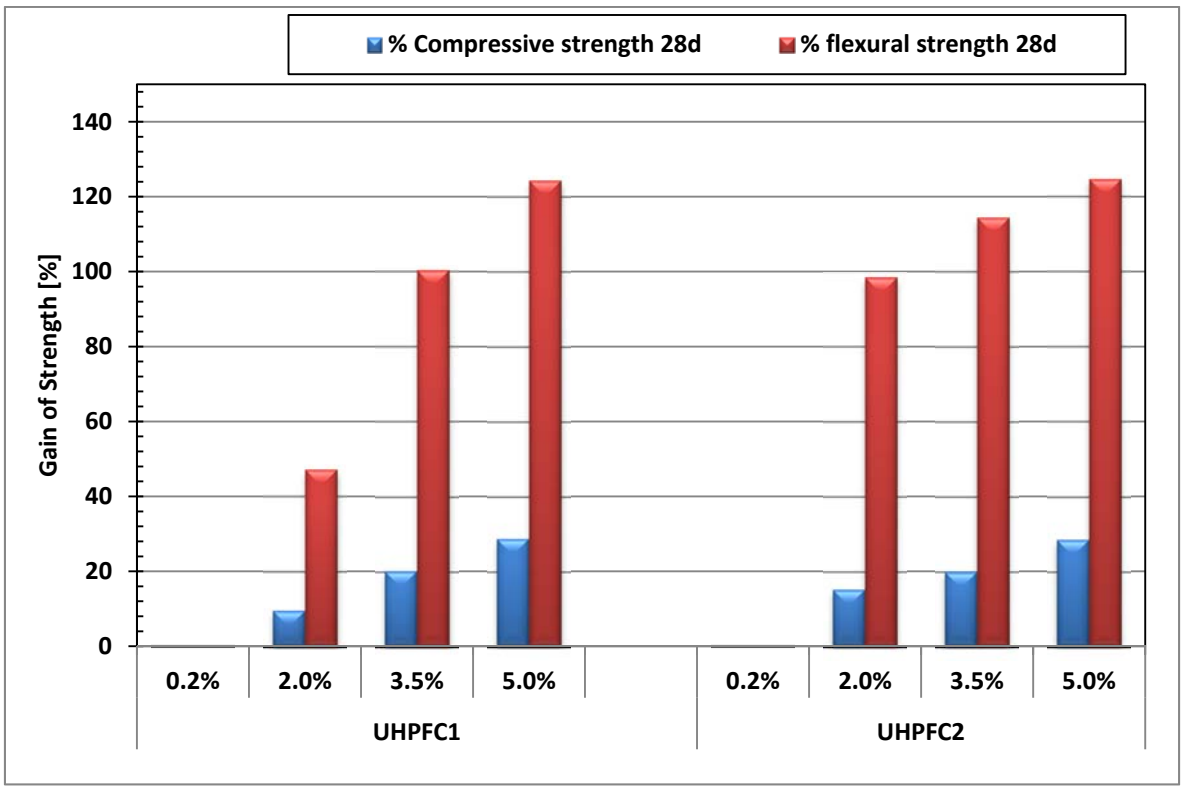


Figure 4 Gain of Compressive and flexural Strength of UHPFC

From the figure 4, it is observed that with increase in fiber percentage, the compressive force also increases with age. At the age of 7 days with 1.5 percentage fiber the compressive strength is 16.36 percent in excess over the strength of reference 17.49 percent in excess of reference mix [25-28]. As the metallic fiber is increased, the compressive strength decreases, but it's more than that control concrete can be seen from the Table 7.

3.4. Importance of dune sands as mineral addition

In order to compare the effectiveness of dune sand as a pozzolanic addition and its effect on the strength development of concrete, it was necessary to develop a concrete with the same composition based on natural pozzolan. It should be noted that the pozzolanic used in cases with the same finesse as used dune sand. It was proven that many studies have been shown the natural pozzolanic can be used as a supplementary material cementitious and can also improve mechanical properties of ultra-high performance concrete [29-32]. Obtained results were given in figure 5 (a, b).

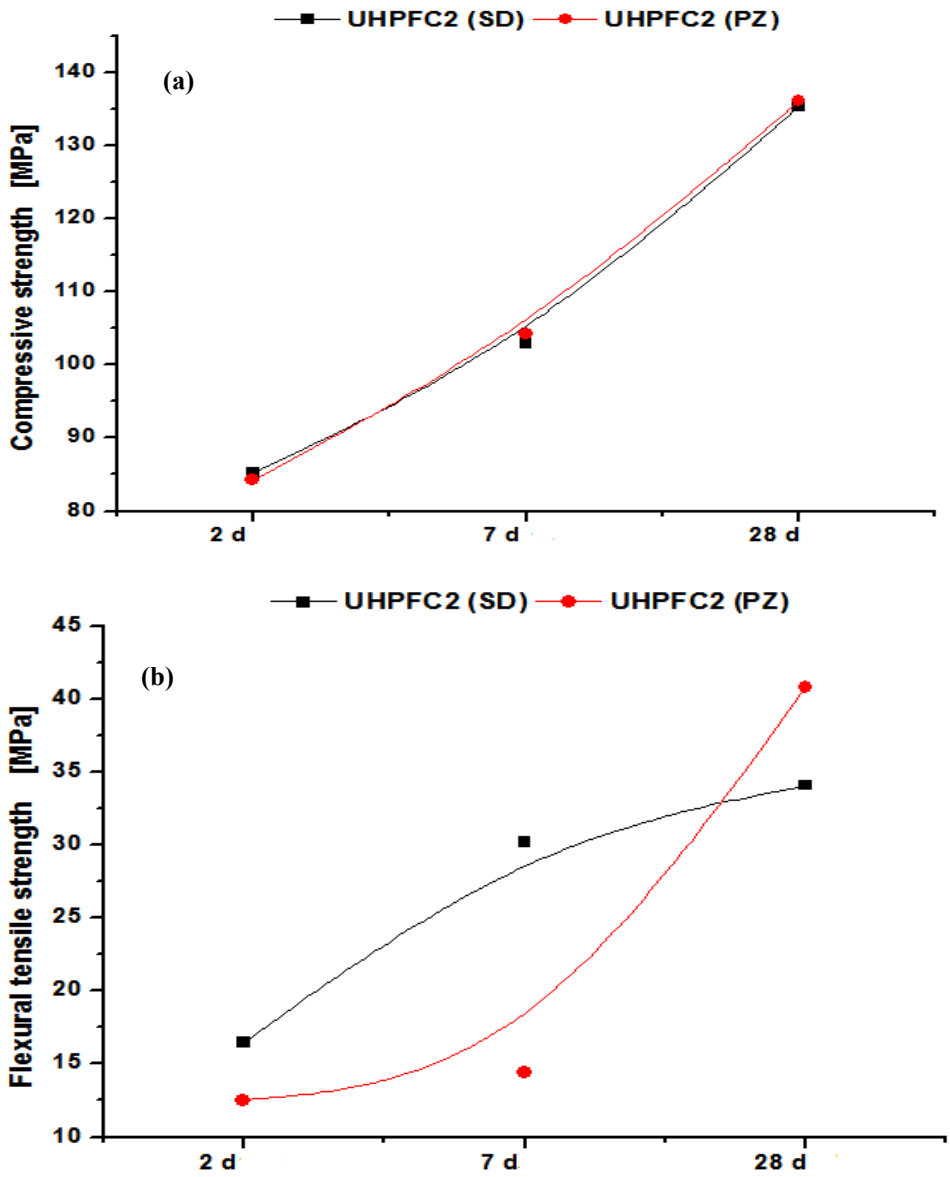


Figure 5 Evolution of Compressive (a) and flexural (b) Strength of studied UHPFC's: Compared to Pozzolan-based UHPFC

Figure 5 presents the evolution of compressive and flexural strength of studied UHPFC's; Compared to Pozzolan-based UHPFC. It is clearly that the compressive and flexural strength of Dune sand-based concretes is better to Pozzlan-based concretes especially at short term of hardening age. The incorporation of dune sand in ultra-high concrete is particularly useful during the first 28 days, where the rate of strength development is considerably higher than pozzolan-based concretes. After 28 days of curing, the incorporation of DS does cause an increase in the rate of strength development. That can be explained by improvement of the compactness and densification of the cement matrix in the presence of finely ground dune sand [10-12, 19-21]. The results of ultra-sonic tests of sand-based concretes showed us that a clear

improvement of the compactness of the concrete and that by the increase of the speed of propagation of the sound within the cement matrix of the UHPFC (DS) (figure 6).

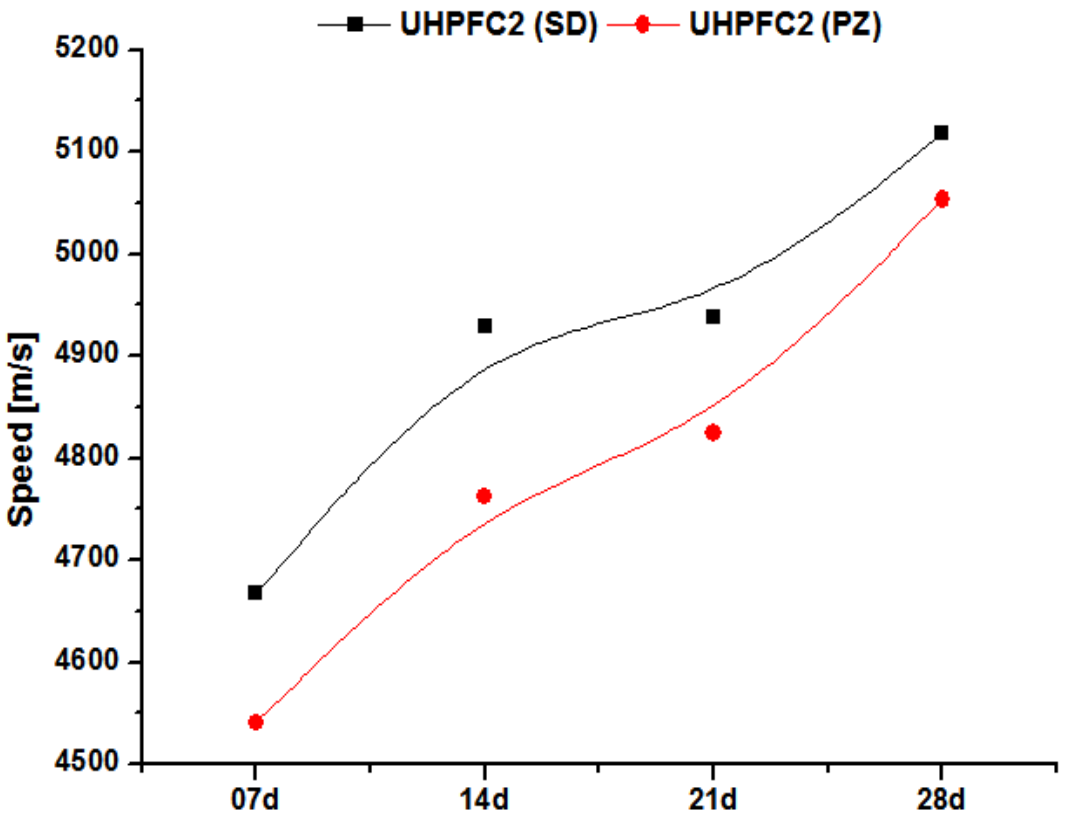


Figure 6 Evolution of ultrasonic velocity as a function of curing time of UHPFC's

3.5. Micro-structural study of UHPFC based on crushed dune sand

A micro-structural study by SEM of studied concretes was conducted to analyze the effect of the crushed dune sand on cementitious hydration products. In Figure 7 gives the cementitious matrix-dune sand aggregates interface in a concrete specimen based on crushed dune sand after 28 days of hydration (with and without fibers).

According those images, it clearly observe the formation of new hydration products from the pozzolanic reaction between crushed dune sand and portlandite (Ca(OH)2) released from hydration of cement (figure 7(a)). Also, it is observed that the dune sand grains (used as fine aggregates) well bonded with cement matrix in both cases of studies i.e. concretes with and without fibers [31-34]. It is also remarkable that crushed dune sand has densified the interfacial area between the fiber and the cement matrix (figure 7(b)).

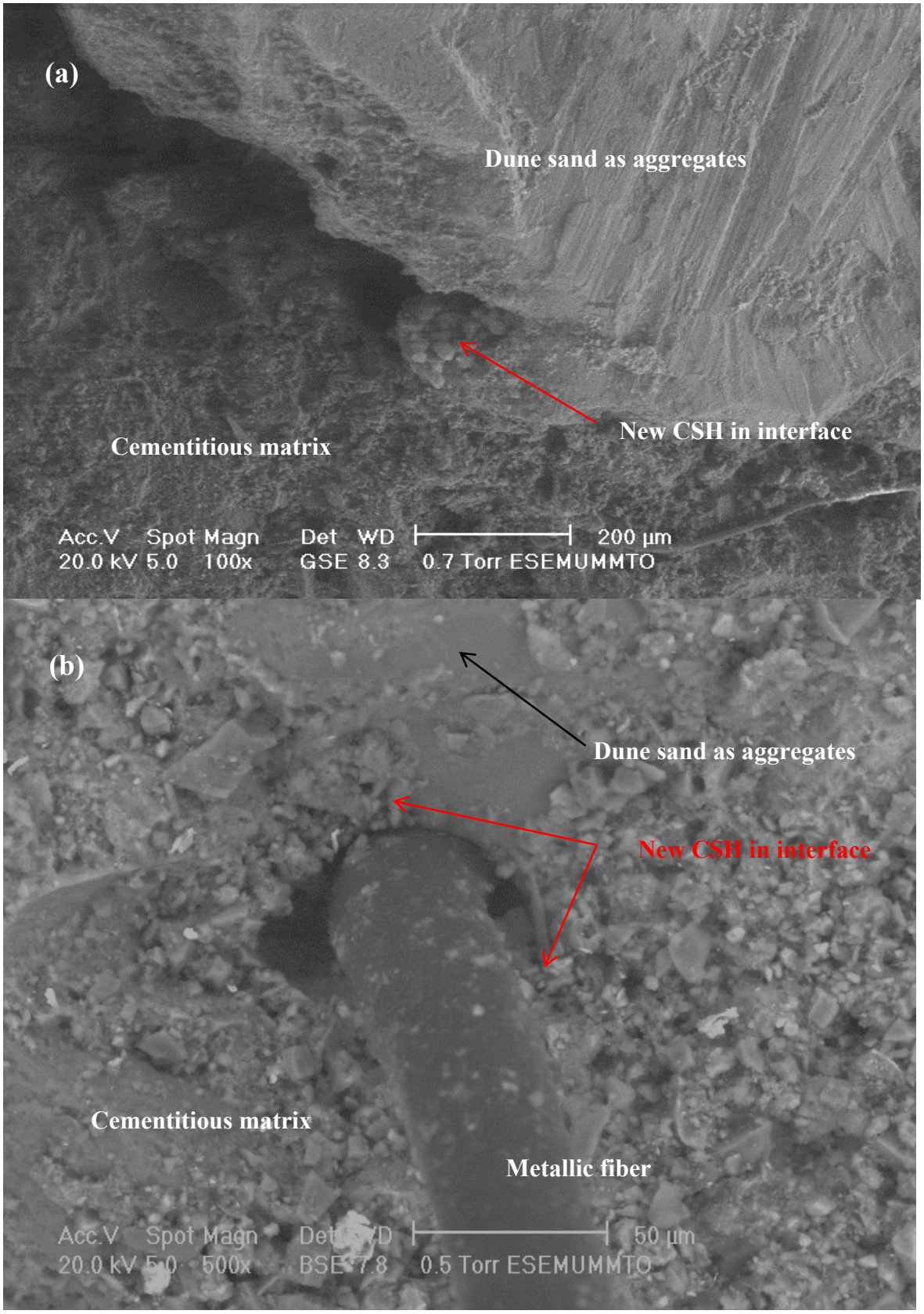


Figure 7 SEM images of studied concretes based on crushed dune sand
(a) Without fibers (b) UHPFC with fibers

4. Conclusion

The importance of valorization and using of dune sands has been discussed in this work. According the results obtained from this study, the following conclusions can be drawn on the Effect of crushed dune sand on the mechanical performance of UPFC with and without fibers:

- The optimal amount of cement substitution by dune sand is 10%.
- The optimum volume of metal fibers is 5%.
- The best variant is the one that substitutes the cement with 10 % dune sand and 5% metal fiber, called uhpfc2.
- The effect of the introduction of pozzolan on the mechanical properties is clear after 28 days.
- The mechanical strengths obtained are in good agreement with the speeds of the ultrasound.
- The introduction of dune sand into the ultra-high performance fiber reinforced concrete composition is advantageous from the point of view of its abundance and low operating cost.
- In light of the above, we can conclude that the development of sand dunes and pozzolan in the manufacture of ultra-high performance fiber concrete with suitable formulations is promising from the point of view of economy and mechanical performance. For this and prospect, the sustainability of the best variant will be studied in aggressive environments and it will be the theme of the ext study.
- The micro-structural study carried by SEM on studied concretes, has showed the beneficial effect of the crushed dune sand on the cementitious hydration products. The interfacial zone of cementitious matrix studied on concrete specimens (with and without fibers) has showed that crushed dune sand can gives the formation new products (CSH) which contributed to the improvement of the mechanical performance of concrete.

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